# Revealed Multilateral Trade Resistance in Gravity Models: A Network Approach

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## Abstract

*The position of countries in the world trade network (WTN) is fundamental in understanding and explaining trade flows between countries. Recent theoretical models introduce these network structures into the traditional gravity model, most notably Anderson and van Wincoop (2003) by introducing the concept of multilateral trade resistance (MTR). Despite these theoretical insights, little has been done to empirically validate these network effects. The concept of MTR remains a black box with many unobservable factors. The key contributions of this paper are the following. First, we capture the network effect of the WTN by the notion of revealed multilateral trade resistance (RMTR), which consists of calculating first-order and second-order network effects of the WTN. Secondly, we show that this network structure is important to explain bilateral trade patterns, by presenting an augmented gravity model, which includes the RMTR. In particular, we characterize the RMTR by two network indicators, degrees and clustering, and show that these indicators have strong and significant, but opposing effects on bilateral trade values. A higher degree raises average bilateral trade values, while a higher clustering coefficient has a negative impact on bilateral trade. Finally, we decompose the effect of the RMTR by studying its effect on the intensive and extensive margins of trade. We find that the effect of degrees is positive and fairly symmetric on both the intensive and the extensive margin of trade. The effect of clustering is, however, positive on the intensive margin, but negative on the extensive margin, indicating competition effects. Hence it appears that countries decrease their variety in exported goods due to competition in the global network. However, they trade their varieties more intensely.* (*JEL* D85, F14)

**Keywords:** gravity, networks, degrees, clustering, trade and multilateral resistance.

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# 1. INTRODUCTION

As trade barriers decline over time, the world gets more and more globally connected: firms search for opportunities to export to new markets and consumers like to import a wealth of variety. This is because of a decline in bilateral barriers to trade (Hummels, 2007), but also because the multilateral interactions between economies are intensified. Recent contributions in the field of international trade focus on these multilateral interactions. Anderson and van Wincoop (2003) (AvW) have famously implemented this idea into the theory of gravity, by introducing the concept of multilateral trade resistance (MTR). Bilateral trade between any country pair is affected by both trading partners' interactions with the rest of the world. The MTR concept captures very well the third-country effect on trade. From more recent research (Arkolakis and Muendler, 2010; Helpman, Melitz and Rubinstein, 2008 (HMR)), we learn, however, that exporting countries or firms are not active in all foreign markets as firms have to overcome a productivity threshold. HMR employ the Melitz (2003) model with fixed costs of exporting and heterogeneous firms into a gravity setting, explaining both the intensive margin (country-level *volume* of exporting firms between country $i$ and $j$) and the extensive margin (country-level *number* of exporting firms between $i$ and $j$) of trade at the country level. As a trade-off, however, no third-country dependence is modeled.[1] Hence some bilateral trade flows have zero values, which AvW did not take into account. As a result, each exporter's and each importer's MTR is unique and determined by each country's international competitiveness, its openness to trade as well as by global competition.

In this paper we combine the concept of MTR with the existence of zero trade flows. By doing so, we bridge the two most recent waves in the theory of the gravity model (Head and Mayer, 2013): the first wave pinpoints the necessity of incorporation of a general equilibrium setting to correctly specify the model (Eaton and Kortum, 2002; AvW); the second wave successfully incorporates heterogeneous firms in the gravity model (HMR; Chaney, 2008; Arkolakis, 2010).We follow an empirical approach to study the impact of MTR on bilateral trade flows in an augmented gravity equation. Our empirical approach to MTR is based on insights from network theory. In particular we introduce two simple network indicators, degrees and clustering. Both network measures, respectively first-order and second-order network effects, jointly signal the main features of the MTR. As such we reveal the theoretical MTR that trading partners are confronted with in reality. Hence our empirical strategy is similar to how the literature deals with the concept of comparative advantages. The latter are unobservable too since they are determined under the non-existing situation of autarky. Actual trade flows show, however, the realized pattern of comparative advantages, the so-called revealed comparative advantages. Our new concept, *revealed multilateral trade resistance (RMTR)*, will be calculated for worldwide bilateral trade flows from 1998 till 2009. Our results show that these network effects are strong and significant in determining bilateral trade, and this on both the intensive and on the extensive margins of trade.

[1] See Appendix II of HMR for more information. Key to the problem is the decomposability of the extensive margin into specific elements for importer, exporter and importer-exporter pairs.

Other empirical network studies in the literature range from descriptive statistics or the topology of the WTN to using network variables in gravity models of trade. Garlaschelli and Loffredo (2004) show descriptive statistics of degrees and reciprocity in an un-weighted version of the WTN, i.e. looking at whether trade links exist or not on the country level. Serrano and Boguñá (2003) and Reyes, Garcia and Lattimore (2007) extend the analysis to weighted versions of the indicators, taking into account trade values between countries. Fagiolo, Reyes and Schiavo (2008) represent the WTN as a dynamic core-and-periphery network, where the typical developed countries are at the core of the network (showing both many and intense trade links), while many developing countries are at the periphery. They then track the evolution of the BRIIC countries (Brazil, Russia, India, Indonesia and China) and see these move towards the core of the network. Closest to our work is that of De Benedictis and Tajoli (2011), who were the first to include network statistics as regressors in a gravity setting. They implement un-weighted degrees as explanatory variables in the Deardorff (1998) variant of the gravity model, which only produces zeros under particular conditions in the model. We extend the analysis to weighted versions of both degrees and clustering and link them to the models of AvW and HMR, while distinguishing between the effects on the margins.

The paper is organized as follows. In section 2, we link our setup to the related literature on gravity and third-country dependency. In section 3, we introduce the empirical methodology to define the revealed MTR. Section 4 presents data and some descriptive statistics. Section 5 presents the results and section 6 concludes.

## 2. RELATION TO THE LITERATURE

### *2.1 Theoretical background*

In this section, we discuss how third-country dependence is taken into account in the gravity equation. The AvW model with only variable trade costs and homogeneous firms implies that firms and/or countries export to all destinations. It's not absolute trade costs that matter, but rather relative trade costs. Bilateral trade does not only depend on the two countries considered, but rather on all trade flows for the exporter and for the importer. The AvW gravity equation is then given by:

$$x_{ij} = \frac{y_i y_j}{y_w}\left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma} \tag{1}$$

with equilibrium price indices:

$$\begin{cases} P_i^{1-\sigma} = \sum_j \left(\frac{t_{ij}}{P_j}\right)^{1-\sigma} \theta_j \\ P_j^{1-\sigma} = \sum_i \left(\frac{t_{ij}}{P_i}\right)^{1-\sigma} \theta_i \end{cases} \tag{2}$$

Aggregate export values $x_{ij}$ from country $i$ to country $j$ are explained by incomes $y_i$ and $y_j$ relative to world income $y_w$, variable trade costs $t_{ij}$, an elasticity of substitution $\sigma > 1$ common to all countries, and the multilateral resistance terms $P_i$ and $P_j$, which also include world income shares $\theta_i \equiv y_i/y_w$. A change in trade costs affects bilateral trade through two channels in this model. For a bilateral drop in trade costs $t_{ij}$, there is on the one hand the direct classical partial equilibrium effect that leads to a rise in bilateral trade $x_{ij}$. On the other hand, and the main contribution of AvW, there is an additional channel that affects trade through the exporter and importer price indices in (2). Both channels together imply the general equilibrium effect. The MTR are a non-linear function of a country's full set of bilateral resistance terms $t_{ij}$ captured by the ideal CES price indices,[2] the common elasticity of substitution and world income shares. These adjust in general equilibrium and lead to the price indices stated in (2). Higher MTRs raise bilateral trade: for a fixed bilateral trade barrier between $i$ and $j$, a higher inward MTR for the importer $P_j$ induces more trade from $i$, since higher barriers between $j$ and the rest of the world reduces the relative price of goods from $i$. Conversely, higher outward MTR for the exporter $P_i$ leads to less demand for goods from $i$, which lowers its relative price, making it more attractive for $j$ to import. Failing to account for this MTR leads to an *upward* bias in estimated trade elasticities. Moreover, this bias can be very large, as the authors show to solve the implausible high trade elasticities generated from the McCallum (1995) border puzzle.

The diversion pattern in the model is so that trade between smaller countries becomes redirected to larger countries. A uniform drop in bilateral trade costs will make bilateral trade more attractive, but due to the MTR effect, bigger importers are less affected by the changes in relative prices, and many changes in trade costs favor exporting to larger importers over smaller importers. This finding will be confirmed through our observed pattern of network variables in section IV. The two main restrictions of the AvW specification of the gravity model are that firstly, trade always exists, even for transport costs tending to infinity. Secondly, the indices can also include non-pecuniary trade costs, home preference bias etc., and are not restricted to observable consumer price indices as confirmed by AvW. It is clear that these theoretically correct MTR are a true black box: the indices themselves are unobservable due to (i) a significant portion of the trade cost function that is unobservable (Anderson and van Wincoop, 2004); (ii) the indeterminacy of the recurrent price indices;[3] and (iii) the definition of the price indices, which can include unmeasured home bias, as noted by AvW, and other unobservables.

The AvW model only has an effect on the intensive margin of trade, while we do see a plethora of zeros in the trade matrix, even at the country level. HMR subsequently implement the extensive margin into their model. Taking into account heterogeneous firms and fixed costs of exporting with asymmetric trade costs, HMR, Chaney (2008) and Arkolakis (2010), *inter alia*, show that firms need to overcome some productivity threshold in order to be able to export to particular destinations. If no firm in a country overcomes this fixed export cost, exports are zero for a given country pair, pinning down the extensive margin of trade.[4] The main gravity equation in HMR is then: [5]

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[2] Given by $P_j = \left[\int \left(p_i(l)t_{ij}\right)^{1-\sigma} dl\right]^{\frac{1}{1-\sigma}}$.

[3] AvW impose symmetric trade costs for the system of equations to render a unique equilibrium.

[4] While Chaney (2008) assumes all countries have access to the same technology with Pareto distributed firm-level productivities, HMR implement both firm-level productivity differences and country-level access to technology differences.

[5] We use a unified notation of the HMR paper for cross-referential ease, i.e. exporter country is $i$, and importer country is $j$.

$$x_{ij} = y_j n_i \left(\frac{c_i t_{ij}}{\alpha P_j}\right)^{1-\sigma} V_{ij} \tag{3}$$

with

$$P_j^{1-\sigma} = \sum_i \left(\frac{c_i t_{ij}}{\alpha}\right)^{1-\sigma} n_i V_{ij}$$

and

$$V_{ij} = \begin{cases} \int_{\varphi_L}^{\varphi_{ij}} \varphi^{1-\sigma} dG(\varphi) \text{ for } \varphi_{ij} \geq \varphi_L \\ 0 \text{ otherwise} \end{cases} \tag{4}$$

Bilateral trade values $x_{ij}$ are governed by importer income $y_j$, the number of producing firms in the exporter country $n_i$, country-level cost differences due to differences in factor prices $c_i$, variable trade costs $t_{ij}$, constant markups $1/\alpha$, importer price indices $P_j$, the common elasticity of substitution $\sigma$ and the trade volume function $V_{ij}$. Equation (4) shows the relationship of $V_{ij}$ with the productivity levels $\varphi$, where $\varphi_L$ denotes the cutoff productivity level needed to be a successful exporter. Note that the productivity levels are identified at the country-pair level, indicated by $\varphi_{ij}$. This implies that the fixed and variable export costs are origin and destination-specific. Assuming a Pareto distribution, and later in the paper a semi-parametric estimation of this productivity distribution of firms in a country, HMR pin down the cut-off productivity level of exporting without needing access to firm-level data, only using country-level data.

Key to the model of HMR is a new channel through which a change in trade costs affects trade: a bilateral drop in trade costs leads to the classical direct increase in bilateral trade, but this effect is magnified by the drop in cutoff productivity that is pinning down the extensive margin; i.e. new, less productive firms are able to export to country $j$, while existing exporters for the given country pair $ij$ are exporting more. A change in variable trade costs thus has an impact on both the intensive and the extensive margin, and these effects run in the same direction.[6] It is the key function $V_{ij}$ that governs this effect: as long as productivity is below the threshold to export, $V_{ij} = 0$. From the moment cutoff productivity is surpassed, $V_{ij}$ becomes positive, and it will increase as productivity rises (see their equation (8)). Failing to account for this leads to a *downward* bias of the trade estimates. In these models however, the MTR channel, or more generally third country dependence, is not present. The price index here is the ideal CES price index accounting for the extensive margin (see their equation (7)). The price index thus takes into account fixed costs and firm heterogeneity, but it does not take into account price indices of other countries, as no general equilibrium structure exists.

Combining the main insights of both waves in the literature, the estimation bias can go either way: not accounting for MTR leads to an upward bias in elasticities, while not accounting for the extensive margin leads to a downward bias. In our empirical validation, it is important that we do account for zero trade flows and for the impact of the network indicators on the intensive and extensive margin of trade. The key function $V_{ij}$ will be the observable basis for our network

[6] A change in fixed costs of exporting affects only the extensive margin through the zero profit condition in the HMR model. However, empirically, it is hard to find a trade variable that only affects the extensive margin.

analysis in Section III to capture both the heterogeneity of productivity and third-country dependence.

### 2.2 MTR and model specification

In these theoretical models MTR is an abstract and unobservable concept. Various empirical approaches have been suggested in the literature to estimate MTR directly. First, AvW propose to estimate the full general equilibrium model using an iterative NLS procedure in Gauss to solve MTR as a function of observables. This approach is feasible in their set-up of 41 regions with symmetric trade flows and a cross-sectional setting. However, it is computationally challenging to extend this to a panel with a large cross section and several years, as we will do in this paper. Additionally, in the presence of asymmetric trade flows, multiple equilibria are possible. Uniqueness is not guaranteed. Hence this procedure has not been adopted widely in the literature. A second approach is to include the so-called 'remoteness term' (Head and Mayer, 2000). This index captures the inverse relationship between distance and GDP of the trading partner as a proxy of how remote these trading partners are. However, AvW argue that this method is 'disconnected from theory', even if the distance term includes all observable trade costs rather than distance only. Thirdly, the most common approach to capture MTR is by including importer and exporter dummies (e.g., Harrigan, 1996; Feenstra, 2004). This approach leads to consistent estimates of the gravity equation in the log-linear form and does not impose much structure on the underlying model (Head and Mayer, 2013).[7] As a fourth solution, one can account for unobserved heterogeneity between cross-sectional units in panel data (including MTR) without losing covariates using a random effects model. However, empirical trade papers favour fixed effects over random effects for two main reasons. With random effects, we force the assumption that the variation of the unobserved heterogeneity is randomly distributed. In most cases, this is too strong of an assumption to make. Additionally, fixed effects models are always consistent, independent of whether the true model is fixed effects or random effects. If the true model is fixed effects then the estimates are also efficient, while the random effects model is inconsistent, unless the true model is random effects. Finally, Baier and Bergstrand (2009) approximate MTR by a linear Taylor approximation to get tractable results. They subsequently show that the approximation error is small for most country pairs. Using OSL estimation is consistent in their setup. The advantage of this method is that all country-level variables can be included in the estimation process, without being absorbed by fixed effects, or without imposing the stringent assumption on normally distributed unobserved heterogeneity of the random effects model. Along similar lines, Koch and LeSage (2009) also present a first-order linearization of the non-linear price index functions, and Straathof (2008) derives an exact log-linearization of the price indices using geometric means, which however suffers from endogeneity in the estimation stage.

In this paper we suggest an alternative empirical approach to capture MTR, namely using network indicators reflecting the RMTR. Even then we have to control for unobserved aspects of third-country dependence, as our RMTR indicators are unlikely to capture the full spectrum of

[7] However, OLS with country level fixed effects is not consistent anymore if spatial dependency exists. See for example Behrens, Ertur and Koch (2007).

multilateral factors affecting trade. We use three alternative estimation methods. First, we use OLS with country fixed effects similar to Harrigan (1996) and Feenstra (2004). Secondly, in order to control in addition for zero trade flows, we use the Poisson Pseudo-Maximum Likelihood (PPML) estimator (Santos-Silva and Tenreyro, 2006). Finally, we follow Baier and Bergstrand (2009). These approaches allow us to estimate and identify the effects of the RMTR indicators, controlling for any remaining unobserved third country dependence factors.

## 3. NETWORK METHODOLOGY

First, let's take a look at the theoretical MTR in equation (2). Some remarks are in order. Firstly, the equilibrium price indices are a function of *all* trade frictions, "including those not directly involving $i$" (AvW). This means that the MTRs also depend on countries that are not $i$ or $j$'s trading partners. In the case of AvW however, all countries are $i$' s trading partners (it is a complete network). In the models with extensive margins, the price indices include fixed costs of exporting, and are also captured inside $V_{ij}$. We will capture the revealed effect of these indirect costs on $i$ or $j$ by using the degrees and clustering measures. Secondly, we don't have information on prices in the model (as the MTR are not just consumer price indices or other observable baskets) and we can only capture the observed part of transport costs, while the unobserved part of these costs can be substantial (Anderson and van Wincoop, 2004). Additionally, we need estimates on the elasticity of substitution to calibrate the model. So in the theoretical MTR, only the GDP shares and some part of the transport costs are observed. We introduce the concept of revealed MTR (RMTR), to capture the effects of the network on bilateral trade. It is revealed, as it is an observable function of both observable and unobservable elements of the theoretical MTR. The revealed notion also captures more than relative prices, including social and economic networks, information networks and other unobservables that might influence both margins of trade. These are all revealed through the existence and intensity of trade volumes. As noted before, there is an analogy with revealed comparative advantage: since the source of comparative advantage can only be determined under autarky, which is unobservable in reality, one has to rely on actual trade flows to 'reveal' the comparative advantage.

The WTN is represented by a network $G = (N, A, W)$. Countries are represented by $n \in N$ nodes in the network. The existence of directed trade flows between countries are given by edges between those nodes ($a_{ij} \in A$), where $i$ is the exporter country and $j$ is the importer country. The complete collection of all countries (nodes) and aggregate trade volumes (edges) is then called the WTN. $A$ is the $n \times n$ binary adjacency matrix with entries:[8]

$$\begin{cases} a_{ij} = 1 \; if \; V_{ij} > 0 \\ a_{ij} = 0 \; otherwise \end{cases}$$

[8] This adjacency matrix relates to the collection of indicator variables $T_{ij}$ in HMR eq. (12): $T_{ij} = 1$ if positive trade exists from $i$ to $j$.

We can also construct the weighted adjacency matrix (Newman, 2010), where the weights of the edges $w_{ij} \in W$ are represented by the trade volumes (as in HMR) so that $V_{ij} = a_{ij}w_{ij}$.[9] In AvW, trade links are symmetric: $a_{ij} = a_{ji}$, never zero, and governed only by variable trade costs and the price indices. In HMR and Chaney (2008), these do not have to be symmetric, and the existence of an edge $a_{ij}$ is governed by variable trade costs, cutoff productivity and the productivity distribution, fixed costs of exporting and the price indices. In HMR, this additionally depends on country-level technology differences.
To reveal the outward multilateral resistance $P_i$, we use the out-degree of an exporter, and similar for the inward multilateral resistance term $P_j$, we use the in-degree of an importer. The un-weighted out-degree $d_i^{out}$ of node $i$ is given by $d_i^{out} = \sum_j a_{ij}$ (total number of active export destinations) and the in-degree $d_j^{in}$ of node $j$ is given by $d_j^{in} = \sum_i a_{ij}$ (total number of active import origins).[10] The weighted out-degree $k_i^{out}$ of node $i$ is given by $k_i^{out} = \sum_j V_{ij}$, and the weighted in-degree $k_j^{in}$ of node $j$ is given by $k_j^{in} = \sum_i V_{ij}$. An appealing characteristic of these degrees is that they have an intuitive economic interpretation. The out-degree of the exporter is a measure for *international competitiveness*, as higher aggregate export volumes indicate that country $i$ has successfully overcome various fixed and variable costs of trade. The in-degree of the importer measures the *import openness* of the country. As a country is more open to imports in general (i.e. the higher the aggregate import volumes), it is more likely to import from country $j$ as well.

Degrees are a first-order characteristic of the network, as they consider only links between the node under consideration and its neighbors. Clustering goes beyond this concept being a second-order characteristic, as it takes into account links between the neighbors of the nodes as well.[11] The local clustering coefficient $C_i$ of node $i$ measures the fraction of a node's neighbors that are themselves connected.[12] Otherwise stated: the clustering coefficient states the expected or average probability that a pair of $i$'s trading partners is itself a trading pair: given that $a_{ij}$ and $a_{ik}$ exist, $C_i$ denotes the probability of $a_{jk}$.[13] More formally (Jackson, 2008):[14]

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[9] One can also argue to use trade values instead of trade volumes. We re-estimated the models in Section V with trade values and obtained similar results, while realizing that we introduce endogeneity into the model by using trade values. In line with HMR, we opt for trade volumes instead.

[10] In an Armington-type model, when goods are differentiated by country of origin, the un-weighted in-degree also represents the number of varieties imported by country $j$.

[11] To avoid confusion with other definitions of clustering: clustering can be seen as a property of the network, or as a means to identify groups or clusters in the network (Opsahl and Panzarasa, 2009). For the purpose of this paper, and for the empirical model in section V, we use the former perspective.

[12] We can differentiate between the global clustering coefficient, which measures the total clustering at the level of the network, and the local clustering coefficient, which is a node characteristic. In the AvW model, the global clustering coefficient is equal to 1, i.e., all possible trade links exist. We use the local clustering coefficient as a regressor in our empirical model.

[13] Note that in the case of the realization of a random network formation process, where each edge is formed independently with a fixed probability $p$, the expected probability of $a_{jk}$ is just $p$, or $E[\Pr(e_{jk})] = p$. However, in non-random networks, such as the WTN, probabilities are not i.i.d., but rather dependent on the existence, and possibly characteristics, of edges $a_{ij}$ and $a_{ik}$. Therefore, the local clustering coefficient expresses this probability.

[14] Note that we use the definition of undirected un-weighted clustering in this paper. We could refine the measure of clustering by going to directed and/or weighted clustering. However, there are eight possible variations of directed

$$C_i = \frac{\sum_{j\neq i,k\neq i,k\neq j} a_{ij}a_{ik}a_{jk}}{\sum_{j\neq i,k\neq i,k\neq j} a_{ij}a_{ik}} \tag{5}$$

The denominator of the right hand side of the equation sums over the triples $\{i, j, k\}$ where $a_{ij}$ and $a_{ik}$ are equal to 1 (active trade links). The numerator then sums over the existing transitive triples. It is clear that $C_i \in (0,1)$ and furthermore that $C_i = 1$ if and only if all possible transitive triples are present that emanate from node $i$. As for the degrees, one can also give an intuitive and appealing economic interpretation of the clustering coefficient. Indeed, the clustering coefficient is a measure of *potential competition effects*. The higher the clustering coefficient, the more competition a country faces as its trading partners engage in trade among themselves. The clustering coefficient as presented here, is an innovation over the concept of HMR: the probability that a country initiates trade with a new country is not only dependent on importer, exporter and importer-exporter characteristics, but it is also dependent on third countries. Moreover, this clustering effect, together with the degrees, has an impact on both the intensive and the extensive margins of trade, as will be confirmed in the empirical part of the paper.

Let's revisit the AvW and HMR model to show how these indicators generalize in a way each model. Firstly, the AvW model does not account for zeros and the effect of the extensive margin channel is silent. Secondly, in terms of the extensive margin of the HMR model, a change in trade costs influences the trade volume function $V_{ij}$. As long as the fixed cost of exporting is not overcome, $V_{ij}$ equals zero and when it is overcome, $V_{ij}$ increases monotonically with the gap between cutoff productivity and real productivity. This is captured in the same way by our notion of degree, the weighted directed link between $i$ and $j$. However, we additionally capture the third country effects of the same exporter, as we aggregate over all active export destinations: $\sum_j V_{ij}$. This is the weighted directed out-degree of country $i$. So, it is not only the extensive margin of $i$ with respect to the direct trading partner $j$ under consideration that influences bilateral trade, but also the effect of the extensive margin of *all* export partners of $i$. Going one step further, the clustering coefficient captures the existence of trade links (the country-level extensive margin defined by HMR) that concern a country's trading partners, rather than its own trade links.

## 4. DATA AND DESCRIPTIVE STATISTICS

Our empirical approach requires data on bilateral trade as well as on various gravity variables. Bilateral trade data are obtained from the BACI dataset from CEPII (Gaulier and Zignago, 2010).[15] This dataset includes bilateral trade values between any two countries from 1998 onwards. The data is complete up to 2009 at the time of writing, so we have a panel of 12 years. The BACI dataset is based on data from the UN Comtrade dataset, but enhanced through

clustering. Additionally, regarding the weights, there are several possible specifications, including arithmetic mean, geometric mean, maximum and minimum tie weights (Barrat et al., 2004; Lopez-Fernandez et al., 2004; Onnela et al., 2005; Zhang and Horvath, 2005) (Opsahl and Panzarasa, 2009). Including all combinations would only clutter exposition and estimation, and is left out of the analysis here.

[15] http://www.cepii.com/anglaisgraph/bdd/baci.htm. The trade values for commodities are reported at the HS6 level and aggregated at the country level.

inclusion of 'missing trade values'.[16] These trade data are used as dependent variable as well as to calculate the network indicators using the open source network analysis program Gephi (Bastian, Heymann and Jacomy, 2009).[17] Data on bilateral distance and geographic indicators are also collected from CEPII.[18] Country characteristics such as GDP are collected from the World Bank (2012). Data on regional trade agreements (RTA) are collected from the website of de Sousa (2012)[19]. They consist of dummy variables equal to one if any RTA was active between any two countries at the given time. WTO membership data has been downloaded from the WTO site.[20] This data set includes information on 238 countries and areas.[21] We drop all observations for which distance or GDP are missing. Consequently the number of countries is reduced to 209.

FIGURE 1 shows the kernel density plots of the distribution of the degrees of the WTN for the years 1998 and 2009. Firstly, panels $a$ and $b$ show the distribution of the in-degrees and out-degrees respectively. Note that, in 1998, there is a small core (countries with many exports destinations) and a large periphery (countries with few destinations). By 2009, the core has increased substantially in terms of the number of countries with many export destinations. A similar distribution and evolution over time is visible for the import patterns. Secondly, the average number of import partners was 90.60 in 1998. This figure increased to 119.76 in 2009, an increase of almost 30%, with a near constant standard deviation between 49.076 and 51.842. A similar pattern arises when considering the out-degrees. Thirdly, there are also very strong positive correlations between the in- and out-degrees of the WTN for the years 1998 and 2009 (correlation coefficients $\rho_{1998} = 0.94$ and $\rho_{2009} = 0.93$), indicating that countries with a lot of import partners also have a lot of export partners. Fourthly, there is a steep growth in the formation of country-level trade links between countries over this arguably short time frame: the directed density of the WTN, expressed as the fraction of existing directed trade flows over total possible trade flows, has increased monotonically from 0.434 in 1998 to 0.568 in 2009 in our sample.[22] This is in line with the findings of – *inter alia* – HMR, who show that i) zeros do exist

[16] See their website for the used methodology. Basically, in network terms, this results in symmetrizing the directed weighted adjacency matrices to fill in non-reported but existing trade flows in the following way: $A^{imp} = [A^{exp}]^T$, where $A$ stands for the weighted adjacency matrix, $imp$ and $exp$ for importer and exporter, and $T$ is the transpose of the matrix. This operation adds another 10% to the number of observations and replaces some observations with true zeros rather than missing observations.

[17] www.gephi.org

[18] http://www.cepii.com/anglaisgraph/bdd/distances.htm.

[19] http://jdesousa.univ.free.fr

[20] www.wto.org

[21] We use countries as defined entries in the CEPII databases. These entries include countries following the definition of the US department of State, aggregated areas and some rest groups. The CEPII database includes 223 defined countries ("areas" not included). Some papers use the Direction of Trade Statistics of the IMF database, however, using the CEPII database, we increase the number of reporters from 157 countries to 209. This leads to a net increase (after balancing later on) of 56% more observations. While this is mainly due to the inclusion of smaller and more remote "countries", it is clear that these observations are not distributed randomly in the WTN, and exclusion will therefore result in biased estimations.

[22] For the undirected density, these are 0.503 in 1998 and 0.655 in 2009, respectively.

at the country level, ii) trade flows are asymmetric in both existence and values or volumes. Panels $c$ and $d$ in figure 1 show the weighted in- and out-degrees of the WTN, where the weights are the natural logarithms of trade volumes measured in tons. Correlations between weighted in- and out-degrees in 1998 and 2009 are $\rho_{1998} = 0.87$ and $\rho_{2009} = 0.88$ respectively. Again there is a significant shift to the right. FIGURE 2 shows the distribution of the clustering coefficients for the years 1998 and 2009. The mean clustering coefficient increases marginally from 0.829 to 0.852 over the analysed period, while there is a clear upward shift of the lower tail of the distribution, leading to a decrease in the variance of the distribution. This implies that the network becomes more and more connected, and this also raises the clustering coefficient.

Finally, combining both indicators of degrees and clustering coefficients, figure 3 shows the clear negative correlation between the clustering coefficients and the in-degrees for the years 1998 and 2009. The negative correlation is stable over time ($\rho_{1998} = -0.97$ and $\rho_{2009} = -0.94$). The negative relation in the upper extreme of the degree spectrum is straightforward to explain, due to the heterogeneity of trading partners: as countries increase the number of trading partners over time, this automatically includes linking with lesser degree countries, which brings down the clustering coefficient (Ravasz et al, 2002; Ravasz and Barabási, 2003). The more interesting part of the spectrum is for the lower degrees with high clustering though.

There are two known possible mechanics that can achieve (near-) complete clustering: the first is due to community formation, the second due to a multi-hub-and-spokes system. Otherwise stated, these mechanics depend on assortative or disassortative mixing: in assortative networks, nodes tend to connect to nodes with the same characteristics, while nodes in disassortative networks tend to connect to nodes that have opposite characteristics.[23] In order to disentangle the possible mechanics, we need to look at the characteristics of the neighbors, and in particular, we look at the average nearest neighbor degree (ANND) of a given vertex.

Community formation as a cause for clustering has been studied by Ravasz and Barabási (2003). If countries tend to group together in close formation, then countries belonging to small communities are constrained to having low degrees. At the same time, those countries exhibit a high clustering coefficient due to the "compact" sub network. If this underlying process holds, we would observe small, dense communities formed by lower-degree countries, i.e. these countries would trade mostly amongst each other in closed formation, in groups (nearly) isolated from each other in the network. In the case of the WTN however, low-degree countries tend to trade (import *and* export) with high-degree countries: the ANND of the 10 lowest-degree countries is unambiguously 1 standard deviation above the mean of the degree distribution, being 170 and above.[24] At the same time, high-degree countries are trading with almost all countries.

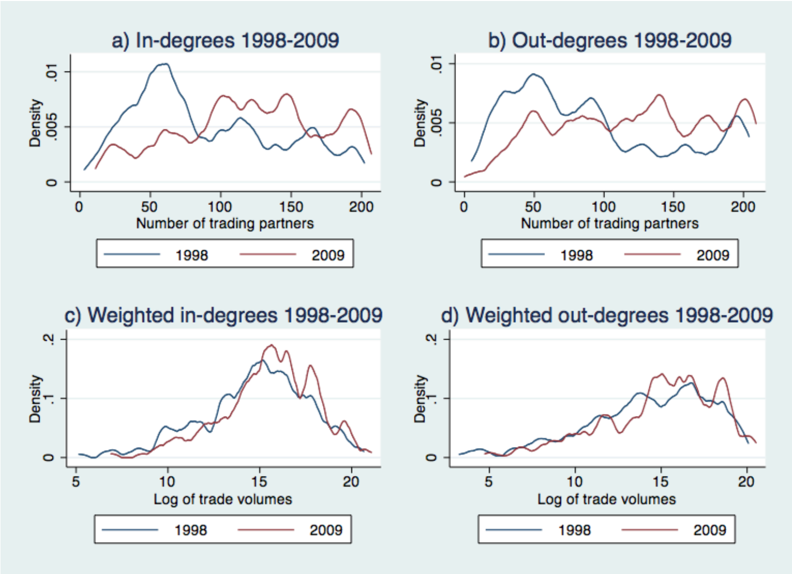
[23] A very simple assortative social network is one where edges represent friendships between individuals, and friendships are more probable when students go to the same school or when they are from the same race for example. A highly disassortative mixing mechanism would be a heterosexual dating club where men connect to women and vice versa.

[24] For example, Saint-Pierre and Miquelon has in- and out-degrees of 18 and 21 respectively, and the in-degrees of its trading partners are 111 as a minimum (Mauritania), 176 as a mean, and 207 as a maximum (Germany). Again, nearly identical results hold for the different degrees used.

This indicates a clear disassortative mixing network and results in trading blocks that are of a multi-hub-and-spokes network.

FIGURE 1

Kernel density plots of degree distributions in the WTN




Notes: Each panel considers years 1998 and 2009. Panel a: In-degree distribution. Panel b: Out-degree distribution. Panel c: Weighted in-degrees. Panel d: Weighted out-degrees.

FIGURE 2

Distribution of the clustering coefficient in the WTN for the years 1998 and 2009

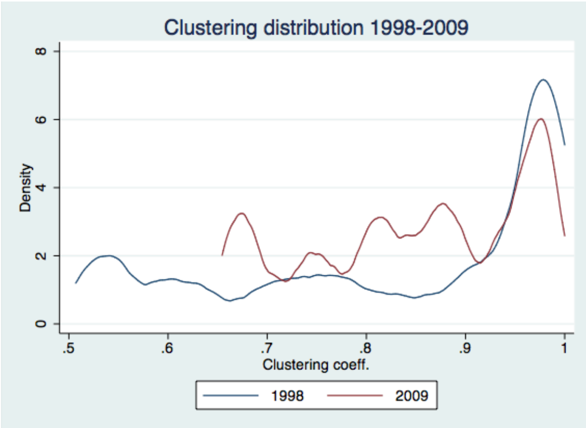
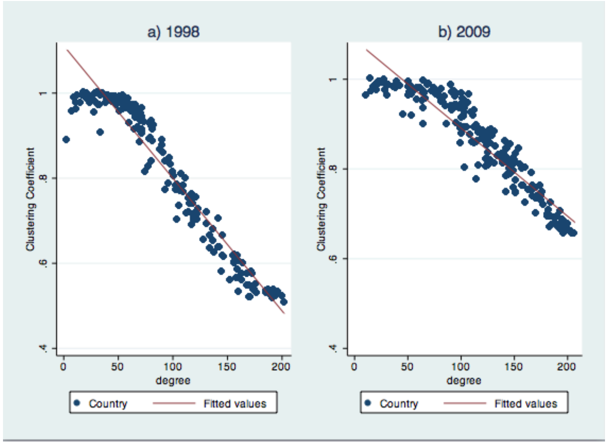



FIGURE 3

Correlation between in-degrees and clustering coefficients for the years 1998 and 2009




## 5. RESULTS

### *5.1 Empirical specification*

We estimate the following augmented gravity model:

$$\ln x_{ijt} = \beta_0 + \beta_1 \ln y_{it} + \beta_2 \ln y_{jt} - \beta_3 \ln t_{ijt} + \beta_4 \ln k_{it}^{out} + \beta_5 \ln k_{jt}^{in} + \beta_6 C_{it} + \beta_7 C_{jt}$$

$$+\eta_i + \zeta_j + v_t + \epsilon_{ijt} \qquad (6)$$

Exports from country $i$ to country $j$ at time $t$ ($x_{ijt}$) is given by a constant $\beta_0$ (including world income $y_w$), the log of the GDPs of both exporter and importer, $y_{it}$ and $y_{jt}$ respectively, the bilateral trade cost function $t_{ijt}$ assumed to be linear in its arguments (with $t_{ijt} = \gamma_1 lndist_{ij} + \gamma_2 contig + \gamma_3 language + \gamma_4 colonizer + \gamma_5 colonial + \gamma_6 WTO_i + \gamma_7 WTO_j + \gamma_8 RTA$ ), the out-degree of the exporter $k_{it}^{out}$, the in-degree of the importer $k_{jt}^{in}$, and the clustering coefficients of exporter and importer, $C_{it}$ and $C_{jt}$ respectively. We will discuss each of these variables in the next paragraph. $\eta_i$, $\zeta_j$ and $v_t$ are exporter, importer and time dummies which capture the remaining theoretically specified MTR factors (cfr. supra). $\epsilon_{ijt}$ is the idiosyncratic error term. Note that the estimated coefficients for bilateral and multilateral trade impediments depend, theoretically speaking, on the elasticity of substitution.

Table 1 gives the estimated coefficients for the panel data, using OLS and importer, exporter and year dummies. Column (1) is a benchmark column, estimating a standard gravity model without the addition of the network measures. This ensures us to compare the stability of the model when the network statistics are added. The variables included in each model as control variables, are standard gravity variables that have shown to be significant in the gravity model. GDP is measured in the natural log of current us dollars. Bilateral distance is in kilometers between the two most populated cities of the trading partners. Contiguity is expressed as a dummy: 1 if both countries share a common border, 0 otherwise. Official common language is also a dummy, with value 1 if both countries share a common official language. Common colonizer is a dummy with value 1 if both countries shared a common colonizer after 1945. Colony is also a dummy, with value 1 if both countries ever had a colonial relationship. WTO membership exporter is a dummy with value 1 if the exporter is a WTO member, and similarly for the importer. The regional trade agreements dummy has value 1 when both countries have some regional trade agreement signed between them and zero otherwise. The estimated parameters are well within the traditional range of gravity estimates.[25] In the OLS setting, we use robust standard errors to cope with possible heteroscedasticity,[26] and clustered standard errors[27] to relax the assumption of independent errors in the model. Regarding fixed effects, we follow the HMR specification, and capture unobserved heterogeneity at the country level and over time using the importer, exporter and year dummies. MTR is taken into account in this approach only as far as these fixed effects capture the unobserved third country dependence.

Since the network indicators reveal various aspects of MTR, we add them both separately and jointly to the specification. As such we are able, firstly, to estimate the impact of each indicator separately. Secondly, we also assess whether and to what extent these factors strengthen or cancel each other out. Note that in none of the specifications, multicollinearity appears to influence the estimated coefficients. Column (2) includes the out-degrees of the exporters and the in-degrees of the importers, while column (3) includes the clustering coefficients of the importers and exporters respectively. Finally, in column (4), both network statistics are simultaneously included.

In column (2), we add the degree statistics. First, we notice that the control variables remain stable; this will be the case for all models considered. Secondly, degrees have a positive and highly significant impact on bilateral trade:[28] an increase of 1 % in an exporter's weighted out-degree increases bilateral trade with 0,12% *per partner* on average. This is actually not a small increment: as total exports of country $i$ to all destinations rises with 10%, *each* existing export

[25] In their meta-analysis of structural gravity estimations, Head and Mayer (2013) find a mean elasticity of distance of around -1.1, while our other benchmark estimates of contiguity and common language are within 1 standard deviation of their findings. We use two parameters to capture colonial ties, where Head and Mayer report 1 meta-coefficient. Finally, our estimate of rta is much lower than the mean of 0.36 reported by the authors. This might be due to the definition of the variable (Head and Mayer include "rta/fta" as a dummy). The GDP coefficients of zero in the estimation are due to our particular use of fixed effects dimensions, and are in line with Baldwin and Taglioni (2006) who suggest that both trade costs and GDP measures do not vary much over a short time frame, as is the case in our panel. Note that estimating the most basic gravity model using only GDP and distance (without inclusion of fixed effects) yields standard coefficients around unity for GDP. However, adding fixed effects turns the GDP coefficients to zero, independent from adding additional control variables, or the use of our RMTR terms. This is also confirmed in our estimates of the Baier and Bergstrand (2009) estimation, where GDP values are around unity, and no fixed effects are specified.

[26] A Breusch-Pagan test for linear heteroscedasticity and a White test for non-linear heteroscedasticity both clearly reject the null of homoscedasticity, and we can therefore conclude that the OLS estimator is at least not BLUE anymore. The most common source of heteroscedasticity in trade data stems from large variation in GDP figures: Similarity of country size shrinks the variances between seller shares and buyer shares (Anderson, 2011), so a more heterogeneous trade network will increase this variance. Similar reasoning goes for distance. Other possibilities are misspecification of the model (including transformed variables), or possible interaction effects.

[27] We are clustering at the country-pair level in our estimation procedures. Since we are interested in country-level variables (network indicators), we can also cluster at the importer or exporter level. The changes in the t-statistics do not influence the significance of the network variables in any conceivable way, while there is some variation in the significance of the control variables: the WTO dummy decreases in significance with the associated clustering level, and the regional trade agreement dummy becomes insignificant in each model.

[28] We have estimated the model using all constellations of un-weighted versus weighted degrees, directed or undirected, exporter versus importer. These variants are highly correlated and give nearly identical results. Results can be obtained from the authors upon request.

destination will induce 1,2% more exports. A similar reasoning holds for the weighted in-degree of the import partner: a 1% increase in weighted in-degree raises bilateral trade with 0,18% per partner on average. This is a clear network effect: being connected to more trading partners in general will increase bilateral trade in particular. Very competitive exporters active in many foreign markets will export more to one particular destination. This could reflect their export experience as they learn from overcoming trade impediments, including fixed and variable costs of exporting. It may also signal a good international reputation because of the quality of their products or cost competitiveness. Similarly, countries importing from many partners appear to be attractive destination markets for their suppliers. Political stability and institutional quality undoubtedly contribute to this. Moreover countries with an active processing role in the global value chain benefit from importing inputs, including intermediate goods, from various other countries.

TABLE 1
OLS gravity panel estimates

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| *ln(GDP exporter)* | -0.00008 | -0.00227 | 0.00169 | 0.00008 |
| | (0.00681) | (0.00705) | (0.00680) | (0.00704) |
| *ln(GDP importer)* | -0.0121 | -0.0148* | -0.00974 | -0.00952 |
| | (0.00638) | (0.00660) | (0.00636) | (0.00656) |
| *ln(distance)* | -1.440*** | -1.440*** | -1.442*** | -1.444*** |
| | (0.0163) | (0.0163) | (0.0163) | (0.0163) |
| *Contiguity* | 0.902*** | 0.894*** | 0.901*** | 0.890*** |
| | (0.0942) | (0.0942) | (0.0944) | (0.0944) |
| *official common language* | 0.670*** | 0.666*** | 0.670*** | 0.666*** |
| | (0.0362) | (0.0361) | (0.0362) | (0.0361) |
| *common colonizer > 1945* | 0.662*** | 0.664*** | 0.662*** | 0.664*** |
| | (0.0447) | (0.0447) | (0.0448) | (0.0447) |
| *colonial ties* | 1.071*** | 1.075*** | 1.074*** | 1.081*** |
| | (0.0882) | (0.0883) | (0.0884) | (0.0886) |
| *WTO membership exporter* | 0.280*** | 0.268*** | 0.274*** | 0.264*** |
| | (0.0284) | (0.0285) | (0.0283) | (0.0284) |
| *WTO membership importer* | 0.252*** | 0.252*** | 0.239*** | 0.232*** |
| | (0.0283) | (0.0285) | (0.0283) | (0.0288) |
| *regional trade agreements* | 0.0170 | 0.0189* | 0.0168 | 0.0185* |
| | (0.00893) | (0.00929) | (0.00891) | (0.00924) |
| *ln(weighted out-degree exporter)* | | 0.121*** | | 0.111*** |
| | | (0.00952) | | (0.00951) |
| *ln(weighted in-degree importer)* | | 0.176*** | | 0.138*** |
| | | (0.00784) | | (0.00778) |
| *clustering coefficient exporter* | | | -0.752*** | -1.166*** |
| | | | (0.0484) | (0.0610) |
| *clustering coefficient importer* | | | -1.037*** | -2.091*** |
| | | | (0.0471) | (0.0806) |
| *Constant* | 16.94*** | 12.54*** | 18.45*** | 15.97*** |
| | (0.317) | (0.372) | (0.322) | (0.389) |
| *R-squared* | 0.7479 | 0.7487 | 0.7482 | 0.7492 |
| *Number of observations* | 245376 | 233204 | 245376 | 233204 |

*Notes: Robust standard errors are in parenthesis, clustering is at the country-pair level. All models are with importer, exporter and year dummies. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

Next, we add the local clustering coefficient to the model in column (3). A higher clustering coefficient has a negative impact on bilateral trade: the more connected a country's trading partners are themselves, the less bilateral trade between these trading partners and the initial country will occur. Since clustering is a measure $\in (0,1)$, a unit increase in clustering of the importer has a negative impact of around 1% on bilateral trade. That is, going from completely absent clustering to total clustering. A more intuitive interpretation is rescaling the clustering coefficient to $\in (0,100)$, so a 1% increase in clustering results in a 0,01% decrease in bilateral trade, and similar for the exporter. Suppose, from the descriptive statistics above, a typical country has had an increase in his clustering coefficient of 20% over the period 1998-2009, this will have a negative impact on bilateral trade of 2% on average. It is intuitive that this measure is of an order of magnitude smaller than the direct network effect of degrees, since it entails actions of a country's trading partners, rather than those of itself. Hence, the first-order effects of the network are larger than the second-order effects. Countries that are highly clustered are subject to intense international competition within their own trade network. As a consequence their bilateral trade with particular trading partners is reduced.

Finally, column (4) combines the degrees and clustering indicators. Again, the signs and significance remain stable, as do the control variables. From the interpretation related to the size of the coefficients above, we can conclude that the joint effect of the network variables on trade is positive: taking into consideration both first-order effects (degrees) and second-order effects (clustering), the net effect of being integrated in the WTN is positive. So although international competition within their own trade networks hampers bilateral trade between two trading partners, this negative effect is more than compensated for by exporting to or importing from many other countries.

Sensitivity analysis, including PPML estimates and Baier and Bergstrand (2009) Taylor approximations are given in appendix 3. When comparing the sign, size and significance of the coefficients of the network statistics, these remain highly robust to different specifications and estimation methods. This indicates that the coefficients are orthogonal to other regressors in the model, and confidence intervals are tighter.

### *5.2 Effects on the margins of trade*

In line with the work of, amongst others, Feenstra (1994), Hummels and Klenow (2005), Bernard et al. (2007), Feenstra and Lee (2008), Lawless (2010) and Van Hove (2010), we decompose trade into the intensive and extensive margins to evaluate the effect of the network indicators on each margin separately. We define the product level as the 6-digit Harmonized System (HS) product code, i.e. how many goods are exported. While AvW only look at the impact of MTR on the intensive margin of trade, HMR point to the mechanics that can influence the extensive margin (firm-level productivity), but do not implement this in a network setting. We estimate this latter effect with our proposed network indicators at the product level. We decompose trade into the most basic notion of margins, such that total trade equals the number of exported products times the average value per product exported (Eaton et al., 2004):[29]

$$X_{ijt} = n_{ijt}\bar{x}_{ijt}$$

Here $X_{ijt}$ denotes total bilateral trade between $i$ and $j$ at time $t$, $n_{ijt}$ the number of products exported from $i$ to $j$ at time $t$ (measured as the number of HS6 product lines in our case) and $\bar{x}_{ijt}$ is the average value per exported product line. $n_{ijt}$ is the extensive margin, $\bar{x}_{ijt}$ reflects the intensive margin. We re-estimate the model with both margins as dependent variable separately.[30] The first 4 columns in table 2 represent the estimations for the intensive margin; the last 4 columns represent the extensive margin results.

First we look at the decomposition of the traditional gravity variables. The interpretation of the margins is straightforward: the extensive margin represents the elasticity of the number of products (HS6 codes in our case) with respect to trade costs, while the intensive margin is the elasticity of the average shipments (Head and Mayer, 2013). The regular determinants of trade remain important in this setting: distance has a negative effect on both margins, while traditional dummies have a positive impact on bilateral trade, with the notable exception of RTA, which becomes insignificant at the intensive margin. We see that the impact of distance is about 2 times larger on the extensive margin than on the intensive margin, i.e. once you trade varieties, much of the distance border has been overcome, and a smaller effect of distance remains on trade volumes.[31] A similar reasoning holds for the other control variables in the model. This is in line with Bernard et al. (2007) and HMR, who show that variable trade costs have an impact on both the extensive and the intensive margin, while HMR even use these trade cost variables to estimate the extensive margin in their two-stage selection model.

When we look at degrees, we see that both margin effects run in the same direction: being well connected will increase both the number of goods you export, as well as the volume of those goods. There is a nice symmetry for the exporter degrees, while the coefficients for the importer are larger on the extensive margin: being well connected in the WTN has a positive impact on the variety of goods for the importer. A positive shock of 1% in the out-degree of the exporter, for example, on any of the margins has a positive impact of around 0,06% on each margin. The joint impact on the margins is then 0,12%. When turning to the clustering coefficient however, things are less obvious. We see a contrasting effect of the clustering coefficient on each margin: the negative relationship holds for the extensive margin, while there is a positive relationship for the intensive margin (and the exporter clustering coefficient turns insignificant on the intensive margin). Simultaneously, the size of the effect of the clustering coefficient is much larger at the extensive margin. A potential interpretation is as follows: an increase of the clustering coefficient has a negative impact on the extensive margin, i.e. the number of goods imported or

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[29] Chaney (2008) further decomposes the extensive margin further into an extensive margin and a compositional margin, and Hummels and Klenow (2005) decompose the margins by weighted shares of products in world trade.

[30] Note that in OLS, $\ln X_{ijt} = \ln n_{ijt} + \ln \bar{x}_{ijt}$. The estimated coefficients of the variables in both margins should sum up to their aggregate counterpart in total trade. This is indeed the case with our results.

[31] For a further discussion, see Abraham et al. (2013).

exported, while this has a positive impact only on imported trade volumes. This is a trade diversion effect at the product level, in line with the idea of comparative advantage: from the moment a country's trading partners start trading themselves, they will gain one or more new varieties to consume. We see that this actually reduces the export of the first country's variety, in the favor of its other trading partner, who now successfully exports a new variety. At the same time, the remaining varieties are imported more intensely. In line with Bernard et al. (2007) and Lawless (2010), the fit of the model for the extensive margin is also better in terms of R-squared when compared to the intensive margin.

TABLE 2

OLS gravity panel estimates on the intensive and extensive margins

| | **Intensive margin** | | | | **Extensive margin** | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| *ln(GDP exporter)* | 0.0104 | 0.00883 | 0.0105 | 0.00877 | -0.0104*** | -0.0110*** | -0.00873** | -0.00855** |
| | (0.00596) | (0.00618) | (0.00596) | (0.00617) | (0.00305) | (0.00315) | (0.00300) | (0.00308) |
| *ln(GDP importer)* | -0.000318 | 0.000257 | -0.000877 | -0.00102 | -0.0117*** | -0.0150*** | -0.00881** | -0.00842** |
| | (0.00537) | (0.00557) | (0.00537) | (0.00558) | (0.00305) | (0.00313) | (0.00301) | (0.00306) |
| *ln(distance)* | -0.473*** | -0.473*** | -0.473*** | -0.473*** | -0.964*** | -0.965*** | -0.966*** | -0.968*** |
| | (0.0103) | (0.0102) | (0.0103) | (0.0102) | (0.0103) | (0.0103) | (0.0103) | (0.0103) |
| *Contiguity* | 0.288*** | 0.285*** | 0.289*** | 0.286*** | 0.616*** | 0.611*** | 0.614*** | 0.607*** |
| | (0.0464) | (0.0464) | (0.0464) | (0.0464) | (0.0712) | (0.0713) | (0.0714) | (0.0717) |
| *off. common lng.* | 0.120*** | 0.116*** | 0.120*** | 0.115*** | 0.543*** | 0.543*** | 0.543*** | 0.543*** |
| | (0.0248) | (0.0247) | (0.0248) | (0.0247) | (0.0212) | (0.0212) | (0.0212) | (0.0212) |
| *com. col. > 1945* | 0.211*** | 0.210*** | 0.211*** | 0.210*** | 0.452*** | 0.455*** | 0.452*** | 0.455*** |
| | (0.0305) | (0.0303) | (0.0305) | (0.0303) | (0.0255) | (0.0255) | (0.0256) | (0.0256) |
| *colonial ties* | 0.244*** | 0.248*** | 0.244*** | 0.247*** | 0.829*** | 0.830*** | 0.833*** | 0.837*** |
| | (0.0523) | (0.0523) | (0.0523) | (0.0523) | (0.0627) | (0.0628) | (0.0629) | (0.0631) |
| *WTO exporter* | 0.0443* | 0.0376 | 0.0435 | 0.0369 | 0.237*** | 0.232*** | 0.232*** | 0.228*** |
| | (0.0224) | (0.0226) | (0.0224) | (0.0226) | (0.0150) | (0.0150) | (0.0147) | (0.0147) |
| *WTO importer* | 0.125*** | 0.123*** | 0.128*** | 0.128*** | 0.127*** | 0.129*** | 0.111*** | 0.103*** |
| | (0.0230) | (0.0231) | (0.0231) | (0.0231) | (0.0157) | (0.0160) | (0.0156) | (0.0160) |
| *rta* | 0.00708 | 0.00824 | 0.00744 | 0.00869 | 0.0103* | 0.0110* | 0.00970* | 0.0101* |
| | (0.00763) | (0.00796) | (0.00763) | (0.00796) | (0.00418) | (0.00434) | (0.00413) | (0.00424) |
| *ln(w. out-deg. exp.)* | | 0.0615*** | | 0.0604*** | | 0.0599*** | | 0.0508*** |
| | | (0.00781) | | (0.00786) | | (0.00421) | | (0.00409) |
| *ln(w. in-deg. imp.)* | | 0.0418*** | | 0.0519*** | | 0.134*** | | 0.0862*** |
| | | (0.00604) | | (0.00613) | | (0.00442) | | (0.00410) |
| *clustering exporter* | | | 0.00535 | 0.0587 | | | -0.756*** | -1.224*** |
| | | | (0.0407) | (0.0515) | | | (0.0238) | (0.0299) |
| *clustering importer* | | | 0.231*** | 0.499*** | | | -1.263*** | -2.582*** |
| | | | (0.0387) | (0.0666) | | | (0.0259) | (0.0440) |
| *Constant* | 7.378*** | 5.840*** | 7.176*** | 5.238*** | 9.546*** | 6.677*** | 11.25*** | 10.70*** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (0.245) | (0.292) | (0.249) | (0.307) | (0.167) | (0.189) | (0.170) | (0.195) |
| *R-squared* | 0.4632 | 0.4643 | 0.4633 | 0.4645 | 0.8224 | 0.8228 | 0.8238 | 0.8253 |
| *Number of obs.* | 245376 | 233204 | 245376 | 233204 | 245376 | 233204 | 245376 | 233204 |

*Notes: Robust standard errors are in parenthesis, clustering is at the country-pair level. All models are with importer, exporter and year dummies. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

TABLE 3

OLS gravity panel estimates with interaction terms between the network indicators and GDP

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| *ln(GDP exporter)* | -0.402*** | 0.00202 | -0.363*** | -0.0140 |
| | (0.0376) | (0.0142) | (0.0374) | (0.0189) |
| *ln(GDP importer)* | -0.353*** | 0.0120 | -0.354*** | -0.00167 |
| | (0.0455) | (0.0145) | (0.0454) | (0.0146) |
| *ln(distance)* | -1.440*** | -1.442*** | -1.443*** | -1.444*** |
| | (0.0162) | (0.0163) | (0.0163) | (0.0163) |
| *Contiguity* | 0.894*** | 0.900*** | 0.890*** | 0.890*** |
| | (0.0942) | (0.0944) | (0.0945) | (0.0944) |
| *official common language* | 0.667*** | 0.670*** | 0.666*** | 0.666*** |
| | (0.0361) | (0.0362) | (0.0361) | (0.0361) |
| *common colonizer > 1945* | 0.663*** | 0.662*** | 0.664*** | 0.664*** |
| | (0.0447) | (0.0448) | (0.0447) | (0.0447) |
| *colonial ties* | 1.074*** | 1.074*** | 1.080*** | 1.081*** |
| | (0.0883) | (0.0884) | (0.0885) | (0.0886) |
| *WTO membership exporter* | 0.262*** | 0.274*** | 0.258*** | 0.264*** |
| | (0.0285) | (0.0283) | (0.0284) | (0.0285) |
| *WTO membership importer* | 0.239*** | 0.239*** | 0.218*** | 0.232*** |
| | (0.0283) | (0.0284) | (0.0285) | (0.0288) |
| *regional trade agreements* | 0.0188* | 0.0168 | 0.0184* | 0.0185* |
| | (0.00928) | (0.00891) | (0.00924) | (0.00924) |
| *ln(weighted out-degree exporter)* | -0.416*** | | -0.377*** | 0.111*** |
| | (0.0507) | | (0.0505) | (0.00951) |
| *ln(weighted in-degree importer)* | -0.297*** | | -0.342*** | 0.138*** |
| | (0.0634) | | (0.0633) | (0.00779) |
| *ln(GDP exporter)*ln(w.out-deg. exp)* | 0.0242*** | | 0.0220*** | |
| | (0.00218) | | (0.00218) | |
| *ln(GDP importer)*ln(w.in-deg. imp)* | 0.0208*** | | 0.0211*** | |
| | (0.00274) | | (0.00274) | |
| *clustering exporter* | | -0.745 | -1.136*** | -1.599** |
| | | (0.425) | (0.0608) | (0.584) |

| | | | | |
|---|---|---|---|---|
| *clustering importer* | | -0.381 | -2.088*** | -1.850*** |
| | | (0.389) | (0.0804) | (0.396) |
| *ln(GDP exporter)*clustering exporter* | | -0.000343 | | 0.0178 |
| | | (0.0171) | | (0.0235) |
| *ln(GDP importer)*clustering importer* | | -0.0274 | | -0.0100 |
| | | (0.0162) | | (0.0164) |
| *Constant* | 29.16*** | 17.92*** | 31.88*** | 16.13*** |
| | (1.376) | (0.554) | (1.377) | (0.675) |
| *R-squared* | 0.7488 | 0.7482 | 0.7493 | 0.7492 |
| *Number of observations* | 233204 | 245376 | 233204 | 233204 |

*Notes: Robust standard errors are in parenthesis, clustering is at the country-pair level. All models are with importer, exporter and year dummies. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

*5.3 Interaction effects*

Intuitively one can imagine that GDP and the network indicators interact: GDP moves with the number of trading partners and trade intensities. Therefore we additionally test the hypothesis that the network effects on trade are more important for high GDP countries and less important for low GDP countries. We explore this possible relationship using interaction terms. Table 3 represents the results from the OLS procedure with importer, exporter and year dummies.[32] When using interaction terms, one cannot interpret the separate coefficients that are also interacted in the same model, i.e. one needs to interpret the combined coefficient of the individual variable and its interaction effect jointly. For example, the impact of the exporter out-degree on bilateral trade is given by the partial derivative of the gravity equation with respect to out-degree. In the case of the log-linear OLS specification, this relates directly to the estimated elasticities:

$$\frac{\partial x_{ij}}{\partial k_i^{out}} = \beta_{k_i^{out}} + \beta_{interaction-k_i^{out}} * \ln GDP_i$$

$$\frac{\partial x_{ij}}{\partial k_i^{out}} = -0.416 + 0{,}0242 * 23.43 \cong 0.15$$

In the last term, we used the mean GDP of 23.43 (see appendix 2) to evaluate the model at the average. It follows directly that the interacted impact of out-degree has a positive effect for larger GDP countries, while it could become negative for small GDP countries.[33] Similar reasoning holds for the other interaction terms. The clustering coefficient interacted with GDP has no significant impact on bilateral trade. This is rather intriguing: clustering affects trade negatively evenly strong, independent of GDP levels. Hence competition effects in a country's network appear to be equally strong regardless of country size.

*5.4 Extensions*

As the network effect on bilateral trade can be different for wealthy countries, rather than only for high GDP countries, we also account for country income by generating GDP per capita figures. We split the sample up in four quartiles, each representing 25% of GDP per capita: the first quartile contains the 25% lowest GDP per capita countries, and so up to the 25% highest GDP per capita countries. We then regress these split samples again per quartile, once for the quartiles attached to the exporter countries, and once for GDP per capita for the importer countries. Here we find some differences across quartiles, with slightly higher coefficients for the second quartile, but differences are small.

The AvW model explicitly models the effects of the outward MTR of the exporter and the inward MTR of the importer. By assuming symmetric trade costs, AvW do not need to model the possible effects of the inward MTR of the exporter (an openness-to-trade effect of the exporter) or similarly the effect of the outward MTR of the importer (a competition effect of the importer). We can empirically differentiate these four effects in our empirical RMTR by including both

[32] The model was also estimated using the Taylor approximation method on the panel, which gave identical estimates for the network indicators.

[33] However, the threshold of the natural log of GDP for the net effect of the out-degrees to become negative is $\frac{0.416}{0{,}0242} = 17{,}19$. In our dataset, this only includes Tuvalu.

out-degrees and in-degrees for importers and exporters. In the model of AvW, we expect these measures to be symmetric to the "main RMTR" we analyzed above. However, we find that the "main RMTR" effects (out-degree of the exporter and in-degree of the importer) are significant and around 5-10 times larger than the "additional RMTR" channels in OLS and PPML estimates. When looking at the effects of the degrees on the margins, the "additional MTR channels" become insignificant on the intensive margin, while all RMTR channels remain significant and strong on the extensive margin, after controlling for clustering as before. Results are in the appendix. This implies two additional findings. Firstly, as far as RMTR can be related to the theoretical MTR, we see that the network effect of revealed trade flows is not symmetric as in AvW, however, both directions of the degrees are significant. Secondly, the export openness of the exporter (in-degree of the exporter) and the competition effect of the importer (out-degree of the importer) are only significant at the extensive margin.

## 6. CONCLUSION

The impact of bilateral trade costs on bilateral trade flows is well documented in the traditional gravity literature. However, since a decade, it has become obvious that the relationship with third countries is a crucial determinant of these bilateral trade flows too. In particular theoretical contributions have focused on these multilateral barriers to trade. Ever since AvW introduced the concept of MTR, it is commonly accepted that the network position of countries is important in explaining trade. The theoretical concept of MTR remains a black box though. We contribute to the existing literature by revealing at least part of this theoretical concept. More in particular, we introduce the empirical concept of 'revealed' MTR, which measures first-order and second-order characteristics of the network by means of in- and out-degrees and clustering. We estimate an augmented gravity equation explaining bilateral export flows by means of classical gravity variables as well as network measures for global trade between 1998 and 2009. From an economic point of view, our three network variables respectively measure import openness, international competitiveness and potential competition effects.

First-order characteristics of the network are calculated as in- and out-degrees of importer and exporter respectively, measuring the weighted number of trading partners. We find a positive impact of out-degrees on bilateral trade, which is as expected since the out-degree is a measure of *international competitiveness*: the more trading partners a country has in general, the more likely it will be to trade with one trading partner in particular. The impact of in-degrees on bilateral trade is positive as well, reflecting the *import openness*: the more open is a country, the more likely it is that one particular exporter trades with that country. Finally, introducing interaction terms, we find that the impact of the degrees has a positive effect for larger countries, while it could become negative for small countries. By contrast, the second-order characteristics, measured by clustering, have a negative impact on bilateral trade. This is an indication of *potential competition effects*. The higher the clustering coefficient, the more competition a country faces as its trading partners engage more in trade among themselves. We find the competition effects in a country's network to be equally strong regardless of country size.

Following the extensive trade literature on the margins of trade, we decompose trade into its intensive and extensive margins to evaluate the effect of the network indicators on each margin separately. Looking at degrees, we see that both margin effects run in the same direction: being well connected will increase both the number of goods you export, as well as the volume of those goods. We see a contrasting effect of the clustering coefficient on each margin: the negative relationship holds for the extensive margin, while there is a positive relationship for the intensive margin. This is an indication of competition effects: it appears that countries decrease their variety in exported goods due to competition in the global network. However, they trade their varieties more intensely.

Finally, we add two extensions to our analysis. First of all, by including GDP per capita instead of GDP, we illustrate that the network effects are similar for countries with varying levels of wealth. Secondly, besides the “main RMTR” effects (i.e. in-degree for importer and out-degree for exporter), we also allow for “additional RMTR” channels (i.e. in-degree for exporter and out-degree for importer). The different results for the “main” and the “additional RMTR” effects indicate that the network effect of revealed trade flows is not symmetric as in AvW. Moreover, the export openness of the exporter (in-degree of the exporter) and the competition effect of the importer (out-degree of the importer) are only significant at the extensive margin.

## APPENDIX 1 – LIST OF COUNTRIES

| | | | |
|---|---|---|---|
| Aruba | Denmark | Lebanon | Rwanda |
| Afghanistan | Dominican Republic | Liberia | Saudi Arabia |
| Angola | Algeria | Libyan Arab Jamahiriya | Sudan |
| Anguilla | Ecuador | Saint Lucia | Senegal |
| Albania | Egypt | Sri Lanka | Singapore |
| Andorra | Eritrea | Lithuania | Saint Helena |
| Netherland Antilles | Western Sahara | Latvia | Solomon Islands |
| United Arab Emirates | Spain | Macau (Aomen) | Sierra Leone |
| Argentina | Estonia | Morocco | El Salvador |
| Armenia | Ethiopia | Moldova, Rep.of | San Marino |
| Antigua and Barbuda | Finland | Madagascar | Somalia |
| Australia | Fiji | Maldives | St. Pierre and Miquelon |
| Austria | Falkland Islands | Mexico | Sao Tome and Principe |
| Azerbaijan | France | Marshall Islands | Suriname |
| Burundi | Micronesia (Federated States of) | Macedonia (the former Yugoslav Rep. of) | Slovakia |
| Belgium and Luxembourg | Gabon | Mali | Slovenia |
| Benin | United Kingdom | Malta | Sweden |
| Burkina Faso | Georgia | Burma (Myanmar) | Seychelles |
| Bangladesh | Ghana | Northern Mariana Islands | Syrian Arab Republic |
| Bulgaria | Guinea | Mozambique | Turks and Caicos Islands |
| Bahrain | Gambia | Mauritania | Chad |
| Bahamas | Guinea-Bissau | Montserrat | Togo |
| Bosnia and Herzegovina | Equatorial Guinea | Mauritius | Thailand |
| Belarus | Greece | Malawi | Tajikistan |
| Belize | Grenada | Malaysia | Tokelau |
| Bermuda | Greenland | New Caledonia | Turkmenistan |
| Bolivia | Guatemala | Niger | East Timor |
| Brazil | Guyana | Norfolk Island | Tonga |
| Barbados | Hong Kong | Nigeria | Trinidad and Tobago |
| Brunei Darussalam | Honduras | Nicaragua | Tunisia |
| Bhutan | Croatia | Niue | Turkey |
| Central African Republic | Haiti | Netherlands | Tuvalu |
| Canada | Hungary | Norway | Taiwan |
| Cocos (Keeling) Islands | Indonesia | Nepal | Tanzania, United Rep. of |
| Switzerland | India | Nauru | Uganda |
| Chile | Ireland | New Zealand | Ukraine |
| China | Iran | Oman | Uruguay |
| Côte d'Ivoire | Iraq | Pakistan | United States of America |
| Cameroon | Iceland | Palestine | Uzbekistan |
| Congo | Israel | Panama | Saint Vincent and the Grenadines |
| Cook Islands | Italy | Pitcairn | Venezuela |
| Colombia | Jamaica | Peru | British Virgin Islands |
| Comoros | Jordan | Philippines | Viet Nam |
| Cape Verde | Japan | Palau | Vanuatu |
| Costa Rica | Kazakstan | Papua New Guinea | Wallis and Futuna |
| Cuba | Kenya | Poland | Samoa |
| Christmas Island | Kyrgyzstan | Korea, Dem. People's Rep. of | Yemen |
| Cayman Islands | Cambodia | Portugal | South Africa |
| Cyprus | Kiribati | Paraguay | Zambia |
| Czech Republic | Saint Kitts and Nevis | French Polynesia | Zimbabwe |
| Germany | Korea | Qatar | |
| Djibouti | Kuwait | Romania | |
| Dominica | Lao People's Democratic Republic | Russian Federation | |

APPENDIX 2 - MAIN VARIABLES AND SUMMARY STATISTICS

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| iso_i | 0 | | | | |
| iso_j | 0 | | | | |
| year | 523338 | 2003.508 | 3.448968 | 1998 | 2009 |
| lnv | 277432 | 7.626643 | 3.740901 | 0 | 19.61737 |
| lni_gdp | 454837 | 23.42584 | 2.453492 | 16.36162 | 30.28562 |
| lnj_gdp | 454837 | 23.42584 | 2.453492 | 16.36162 | 30.28562 |
| lndist | 523338 | 8.815176 | .8388263 | .1734625 | 9.901043 |
| contig | 523338 | .0129094 | .1128841 | 0 | 1 |
| comlang_off | 523338 | .1690838 | .3748263 | 0 | 1 |
| colony | 523338 | .0102572 | .1007573 | 0 | 1 |
| comcol | 523338 | .1166435 | .3209954 | 0 | 1 |
| wto_i | 523338 | .6472853 | .4778153 | 0 | 1 |
| wto_j | 523338 | .6472853 | .4778153 | 0 | 1 |
| rta | 523338 | .0664828 | .2491245 | 0 | 1 |
| lni_windeg | 497631 | 15.24892 | 2.678674 | 3.553518 | 21.47228 |
| lni_woutdeg | 521248 | 14.6485 | 3.382247 | 1.102604 | 20.91874 |
| lnj_windeg | 497631 | 15.24892 | 2.678674 | 3.553518 | 21.47228 |
| lnj_woutdeg | 521248 | 14.6485 | 3.382247 | 1.102604 | 20.91874 |
| i_clus | 523338 | .8351333 | .1341422 | 0 | 1 |
| j_clus | 523338 | .8351333 | .1341422 | 0 | 1 |

- iso_i: Identifier exporter country on the ISO 3 letter country code.
- iso_j: identifier importer country on the ISO 3 letter country code.
- year: The year of the observation.
- lnv: Log of directed trade value. (Original trade value is in thousands of dollars).
- lni_gdp: Log of GDP of country i in a given year. (Original GDP is measured in dollars).
- lnj_gdp: Log of GDP of country j in a given year. (Original GDP is measured in dollars).
- lndist: Log of distance between country-pair, measured in kilometers.
- contig: Contiguity dummy: 1 if sharing a common border.
- comlang_off: Official language dummy: 1 if sharing a common official language.
- colony: Colonial dummy: 1 if both countries were ever in a colonial relationship.
- comcol: Colonial dummy: 1 if both countries share a common colonizer after 1945.
- wto_i: WTO membership dummy: 1 if country i is a member of the WTO in a given year.
- wto_j: WTO membership dummy: 1 if country j is a member of the WTO in a given year.
- rta: Regional Trade Agreement dummy: 1 if both countries in a country-pair had a trade agreement in effect in a given year.
- lni_windeg: Weighted in-degree of the exporter country, measured as the sum of total export volumes from i in a given year.
- lni_woutdeg: Weighted out-degree of the exporter country, measured as the sum of total export volumes from i in a given year.
- lnj_windeg: Weighted in-degree of the importer country, measured as the sum of total import volumes to j in a given year.

- Lnj_woutdeg: Weighted out-degree of the importer country, measured as the sum of total import volumes to j in a given year.
- i_clus: Clustering coefficient of exporter i in a given year.
- j_clus: Clustering coefficient of importer j in a given year.

## APPENDIX 3 – SENSITIVITY ANALYSIS

OLS with the country-level dummies is consistent but not efficient in the presence of heteroscedastic errors. Following Santos-Silva and Tenreyro (2006), we also estimate the model using Poisson pseudo-maximum likelihood, as this procedure performs better than OLS in the presence of heteroscedasticity. In this case, we estimate a panel model including importer, exporter, year and country-pair dummies to capture most of the unobserved heterogeneity, while still allowing for estimation of the network variables, as these move in the country-level and time dimension not captured by the fixed effects. We confirm the size, significance and sign of the previous estimates, with the notable of the clustering coefficient, which now increases an order of magnitude in size.

TABLE A1

PPML gravity panel estimation

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| *ln(GDP exporter)* | 0.00882 | 0.00209 | 0.00939 | 0.00213 |
| | (0.00968) | (0.00856) | (0.00949) | (0.00838) |
| *ln(GDP importer)* | -0.00452 | -0.0118 | -0.00358 | -0.01000 |
| | (0.0100) | (0.00896) | (0.00994) | (0.00892) |
| *WTO exporter* | 0.549*** | 0.474*** | 0.540*** | 0.473*** |
| | (0.0509) | (0.0487) | (0.0502) | (0.0472) |
| *WTO importer* | 0.527*** | 0.420*** | 0.520*** | 0.426*** |
| | (0.0477) | (0.0452) | (0.0489) | (0.0465) |
| *regional trade agreement* | -0.0122 | -0.00795 | -0.0145 | -0.00927 |
| | (0.0157) | (0.0126) | (0.0166) | (0.0127) |
| *ln(weighted out-degree* | | 0.216*** | | 0.217*** |
| *exporter)* | | (0.0254) | | (0.0231) |
| *ln(weighted in-degree* | | 0.176*** | | 0.164*** |
| *importer)* | | (0.0334) | | (0.0323) |
| *clustering exporter* | | | -0.452*** | -0.746*** |
| | | | (0.0652) | (0.0966) |
| *clustering importer* | | | -0.356*** | -0.945*** |
| | | | (0.0586) | (0.179) |
| *BIC* | 7.38221e+09 | 6.76448e+09 | 7.30981e+09 | 6.63803e+09 |
| *Number of observations* | 243335 | 230994 | 243335 | 230994 |

*Notes: Robust standard errors are in parenthesis. All models are with importer, exporter, country-pair and year dummies. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. Since R-squared fitted values are not optimized for panel PPML, we use the Bayesian Information Criterion (BIC) instead to indicate model fit. The panel consists of the years from 1998 to 2009.*

Since we are actually aiming to capture country-level variables that move over time, estimating a full-fledged fixed effects model using importer and exporter time varying dummies would absorb our variables of interest. Therefore we estimated the model with country and time dummies separately. We realize that trade costs can vary over time, so not correcting for the time varying dimension of the country-level characteristics can induce a bias in the estimates, since MTR is not adequately controlled for. If one is willing to follow the reasoning by Baldwin and Taglioni (2006) that on average, trade costs do not change that fast over such a short time frame, the bias resulting from this time-varying effect of the MTR will be relatively small.

TABLE A2

Baier and Bergstrand (2009) Taylor approximation, cross-section 2005

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| *ln(GDP exporter)* | 1.077*** | 0.939*** | 0.796*** | 0.602*** |
| | (0.00643) | (0.0129) | (0.0118) | (0.0154) |
| *ln(GDP importer)* | 0.853*** | 0.430*** | 0.685*** | 0.349*** |
| | (0.00627) | (0.0177) | (0.0109) | (0.0175) |
| *ln(distance)** | -1.427*** | -1.421*** | -1.441*** | -1.434*** |
| | (0.0225) | (0.0222) | (0.0215) | (0.0213) |
| *contiguity** | 0.717*** | 0.726*** | 0.735*** | 0.742*** |
| | (0.105) | (0.102) | (0.106) | (0.102) |
| *official common language** | 0.511*** | 0.512*** | 0.598*** | 0.589*** |
| | (0.0529) | (0.0511) | (0.0519) | (0.0498) |
| *common colonizer > 1945** | 0.786*** | 0.772*** | 0.824*** | 0.806*** |
| | (0.0669) | (0.0647) | (0.0654) | (0.0628) |
| *colonial ties** | 1.120*** | 1.138*** | 1.073*** | 1.095*** |
| | (0.101) | (0.0965) | (0.103) | (0.0990) |
| *WTO membership exporter* | 0.506*** | 0.611*** | 0.164*** | 0.264*** |
| | (0.0477) | (0.0473) | (0.0476) | (0.0471) |
| *WTO membership exporter* | 0.293*** | 0.282*** | 0.0930* | 0.142*** |
| | (0.0405) | (0.0399) | (0.0403) | (0.0395) |
| *regional trade agreements** | 0.00394 | 0.0126 | -0.0365 | -0.0288 |
| | (0.0463) | (0.0450) | (0.0448) | (0.0436) |
| *ln(weighted out-degree exporter)* | | 0.157*** | | 0.195*** |
| | | (0.0129) | | (0.0121) |
| *ln(weighted in-degree importer)* | | 0.541*** | | 0.492*** |
| | | (0.0210) | | (0.0206) |
| *clustering exporter* | | | -8.385*** | -8.861*** |
| | | | (0.282) | (0.277) |
| *clustering importer* | | | -5.339*** | -3.980*** |
| | | | (0.254) | (0.256) |
| *constants* | 96.30*** | 97.71*** | 119.7*** | 119.7*** |
| | (2.211) | (2.190) | (2.185) | (2.167) |
| *R-squared* | 0.665 | 0.680 | 0.686 | 0.700 |
| *Number of observations* | 21188 | 21188 | 21188 | 21188 |

*Notes: Taylor approximated trade cost variables are indicated with an asterisk (*). Robust standard errors are in parenthesis, clustering is at the country-pair level. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level.*

To be more rigorous however, we additionally estimate the model using the Baier and Bergstrand (2009) Taylor approximation method for trade costs. This allows us to estimate the country-level variables while accounting for an approximation of the MTRs.[34] BB estimate the model using distance and a border dummy, we extend the trade cost function to include also common language, common colonizer after 1945, colonial ties and regional trade agreements dummies as transformed control variables in Table A2.

TABLE A3

Baier and Bergstrand (2009) Taylor approximation, panel setting

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| *ln(GDP exporter)* | 0.635*** | 0.403*** | 0.647*** | 0.380*** |
| | (0.00479) | (0.00595) | (0.00495) | (0.00615) |
| *ln(GDP importer)* | 0.481*** | 0.202*** | 0.495*** | 0.192*** |
| | (0.00480) | (0.00578) | (0.00495) | (0.00581) |
| *ln(distance)** | -1.026*** | -1.197*** | -1.045*** | -1.191*** |
| | (0.0210) | (0.0187) | (0.0206) | (0.0184) |
| *contiguity** | 1.596*** | 1.274*** | 1.558*** | 1.284*** |
| | (0.103) | (0.0897) | (0.101) | (0.0886) |
| *official common language** | 0.697*** | 0.604*** | 0.690*** | 0.619*** |
| | (0.0484) | (0.0432) | (0.0477) | (0.0425) |
| *common colonizer > 1945** | 0.632*** | 0.640*** | 0.634*** | 0.653*** |
| | (0.0585) | (0.0523) | (0.0578) | (0.0518) |
| *colonial ties** | 0.853*** | 1.000*** | 0.867*** | 1.012*** |
| | (0.142) | (0.117) | (0.138) | (0.113) |
| *WTO membership exporter* | 0.945*** | 0.692*** | 0.938*** | 0.696*** |
| | (0.0226) | (0.0226) | (0.0225) | (0.0225) |
| *WTO membership exporter* | 0.805*** | 0.534*** | 0.801*** | 0.537*** |
| | (0.0222) | (0.0231) | (0.0221) | (0.0228) |
| *regional trade agreements** | 0.00894 | 0.00847 | 0.00892 | 0.00853 |
| | (0.00996) | (0.00985) | (0.00999) | (0.00986) |
| *ln(weighted out-degree exporter)* | | 0.435*** | | 0.461*** |
| | | (0.00617) | | (0.00663) |
| *ln(weighted in-degree importer)* | | 0.592*** | | 0.596*** |
| | | (0.00760) | | (0.00788) |
| *clustering exporter* | | | -0.300*** | -0.974*** |
| | | | (0.0463) | (0.0573) |
| *clustering importer* | | | -0.135** | -0.882*** |
| | | | (0.0463) | (0.0505) |
| *constant* | -21.20*** | -25.06*** | -21.46*** | -23.28*** |
| | (0.171) | (0.156) | (0.185) | (0.175) |
| *R-squared* | 0.6097 | 0.6481 | 0.6148 | 0.6542 |
| *Number of observations* | 245376 | 233204 | 245376 | 233204 |

*Notes: Taylor approximated trade cost variables are indicated with an asterisk (*). Robust standard errors are in parenthesis, clustering is at the country-pair level. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

Since the BB approach has been developed for cross-sectional analysis, we include both a cross-section for the year 2005, and also a panel estimation in line with our other models. The results for the panel estimates are given in table A3. To be clear, the typical distance variables are now

[34] Details of the data procedures are available in Appendix 3.

transformed into a Taylor approximation, indicated by an asterisk (*) next to the transformed variable. All control variables remain stable. More importantly, all results for the network measures still hold: the impact of the weighted degrees on bilateral trade is significant and positive, and for clustering this impact is significant and negative.

TABLE A4

OLS and PPML gravity panel estimates with the 4 degree channels

| | (1) OLS | (2) OLS | (3) PPML | (4) PPML |
|---|---|---|---|---|
| *ln(GDP exporter)* | -0.00281 | 0.000926 | -0.00917 | -0.00698 |
| | (0.00719) | (0.00718) | (0.00734) | (0.00730) |
| *ln(GDP importer)* | -0.0143* | -0.00980 | -0.0145 | -0.0124 |
| | (0.00669) | (0.00665) | (0.00836) | (0.00829) |
| *ln(distance)* | -1.443*** | -1.447*** | | |
| | (0.0162) | (0.0163) | | |
| *Contiguity* | 0.885*** | 0.880*** | | |
| | (0.0942) | (0.0945) | | |
| *official common language* | 0.666*** | 0.666*** | | |
| | (0.0361) | (0.0361) | | |
| *common colonizer > 1945* | 0.665*** | 0.665*** | | |
| | (0.0447) | (0.0448) | | |
| *colonial ties* | 1.083*** | 1.090*** | | |
| | (0.0885) | (0.0888) | | |
| *WTO membership exporter* | 0.266*** | 0.262*** | 0.382*** | 0.399*** |
| | (0.0287) | (0.0287) | (0.0513) | (0.0472) |
| *WTO membership importer* | 0.244*** | 0.227*** | 0.372*** | 0.379*** |
| | (0.0286) | (0.0288) | (0.0414) | (0.0428) |
| *regional trade agreements* | 0.0197* | 0.0200* | -0.00778 | -0.00942 |
| | (0.00946) | (0.00941) | (0.0121) | (0.0127) |
| *ln(weighted in-degree exporter)* | 0.0426*** | 0.0171 | 0.154*** | 0.135*** |
| | (0.00901) | (0.00908) | (0.0239) | (0.0236) |
| *ln(weighted out-degree exporter)* | 0.114*** | 0.0967*** | 0.185*** | 0.179*** |
| | (0.0101) | (0.0101) | (0.0263) | (0.0252) |
| *ln(weighted in-degree importer)* | 0.167*** | 0.135*** | 0.166*** | 0.159*** |
| | (0.00802) | (0.00793) | (0.0308) | (0.0302) |
| *ln(weighted out-degree importer)* | 0.0462*** | 0.0220** | 0.125*** | 0.115*** |
| | (0.00757) | (0.00755) | (0.0231) | (0.0226) |
| *clustering exporter* | | -1.709*** | | -1.291*** |
| | | (0.0811) | | (0.188) |
| *clustering importer* | | -2.182*** | | -0.885*** |
| | | (0.0829) | | (0.172) |
| *Constant* | 11.48*** | 16.22*** | | |
| | (0.402) | (0.431) | | |
| *R-squared* | 0.7483 | 0.7493 | . | . |
| *BIC* | . | . | 6.47197e+09 | 6.33049e+09 |
| *Number of observations* | 227691 | 227691 | 225438 | 225438 |

*Notes: Robust standard errors are in parenthesis, clustering is at the country-pair level. OLS models are with importer, exporter and year dummies. PPML include additional country-pair fixed effects. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

We notice an increase in the size of the coefficient, compared to the main results presented earlier. Using this method, a 1% increase in clustering has a negative effect of between 0,4 and 0,9% on bilateral trade, an order of magnitude larger than the results from the main table. Tables A4 presents the OLS and PPML panel estimates using the 4 degrees approach as proposed in section *5.4 Extensions*. Table A5 presents the same approach, decomposed on the margins.

TABLE A5

OLS gravity panel estimates of the 4 degree channels on the margins

| | **Intensive margin** | | **Extensive margin** | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *ln(GDP exporter)* | -0.0109*** | -0.00709* | 0.00819 | 0.00817 |
| | (0.00321) | (0.00314) | (0.00630) | (0.00630) |
| *ln(GDP importer)* | -0.0155*** | -0.00991** | 0.00127 | 0.000230 |
| | (0.00317) | (0.00309) | (0.00564) | (0.00565) |
| *ln(distance)* | -0.966*** | -0.970*** | -0.474*** | -0.474*** |
| | (0.0103) | (0.0103) | (0.0102) | (0.0102) |
| *contiguity* | 0.605*** | 0.601*** | 0.282*** | 0.283*** |
| | (0.0713) | (0.0717) | (0.0464) | (0.0464) |
| *off. common lng.* | 0.542*** | 0.542*** | 0.116*** | 0.116*** |
| | (0.0212) | (0.0212) | (0.0247) | (0.0247) |
| *com. col. > 1945* | 0.456*** | 0.456*** | 0.209*** | 0.210*** |
| | (0.0256) | (0.0256) | (0.0303) | (0.0303) |
| *colonial ties* | 0.836*** | 0.844*** | 0.250*** | 0.249*** |
| | (0.0629) | (0.0633) | (0.0524) | (0.0523) |
| *WTO exporter* | 0.229*** | 0.226*** | 0.0385 | 0.0376 |
| | (0.0150) | (0.0148) | (0.0228) | (0.0228) |
| *WTO importer* | 0.123*** | 0.102*** | 0.121*** | 0.125*** |
| | (0.0160) | (0.0160) | (0.0231) | (0.0231) |
| *rta* | 0.0121** | 0.0119** | 0.00796 | 0.00846 |
| | (0.00441) | (0.00428) | (0.00813) | (0.00812) |
| *ln(w. in-deg. exp.)* | 0.0501*** | 0.0264*** | -0.00753 | -0.00923 |
| | (0.00411) | (0.00399) | (0.00766) | (0.00778) |
| *ln(w. out-deg. exp.)* | 0.0510*** | 0.0353*** | 0.0629*** | 0.0614*** |
| | (0.00445) | (0.00431) | (0.00833) | (0.00839) |
| *ln(w. in-deg. imp.)* | 0.124*** | 0.0835*** | 0.0424*** | 0.0517*** |
| | (0.00447) | (0.00415) | (0.00623) | (0.00629) |
| *ln(w. out-deg. imp.)* | 0.0435*** | 0.0125** | 0.00203 | 0.00892 |
| | (0.00445) | (0.00423) | (0.00577) | (0.00584) |
| *clustering exporter* | | -1.731*** | | 0.0229 |
| | | (0.0401) | | (0.0681) |
| *clustering importer* | | -2.701*** | | 0.525*** |
| | | (0.0449) | | (0.0684) |
| *constant* | 5.566*** | 10.95*** | 5.898*** | 5.236*** |
| | (0.206) | (0.216) | (0.316) | (0.342) |
| *R-squared* | 0.4641 | 0.4643 | 0.8231 | 0.8259 |
| *Number of observations* | 227691 | 227691 | 227691 | 227691 |

*Notes: Robust standard errors are in parenthesis, clustering is at the country-pair level. All models are with importer, exporter and year dummies. Significance is given by * at the 5% level, ** at the 1% level and *** at the 0,1% level. The panel consists of the years from 1998 to 2009.*

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